TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

OUTI RASK

SUPPORTING THE LEARNING AT WORK OF AUTOMATION ENGINEERS IN THE ADOPTION OF NEW TECHNOLOGIES

Licentiate of Science Thesis

Supervisors:
professor Seppo Kuikka and
professor Matti Vilkko

Abstract

OUTI RASK: Supporting the Learning at Work of Automation Engineers in the Adoption of New Technologies
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Automation engineering is an engineering discipline the objective of which is to design and implement automated functioning of industrial processes and machines. The output of automation engineering is an autonomously performing system that is controlled by an automation system. Making production processes more flexible and safe is a current trend in the industry. This increases the complexity of the processes and machines, and requires adaptability from the automation systems. Thus, also new kinds of competences, knowledge as well as work practices are expected from automation engineers who design automation systems.

The focus in this thesis is on automation engineers' learning at work and how this learning process can be supported with computer-assisted technologies. Engineers' learning process is based on the knowledge of the automation engineers' core task which is investigated with the help of the Core-Task Analysis method (Norros 2004). The core task of automation engineering work is refined with the ideas of the process model of learning at work introduced by Järvinen and Poikela (Järvinen & Poikela 2001). The model combines three well-known learning theories: individual's experiential learning introduced by Kolb (Kolb 1984), the theory of the knowledge creating company introduced by Nonaka and Takeuchi (Nonaka & Takeuchi 1995), and finally the 4I organizational learning framework introduced by Crossan, Lane, and White (Crossan et al. 1999). In this study the focus is on the levels of individuals' and teams' learning at work.

Research material was collected with two methods: semi-structured theme interviews and workshops. All together 18 automation engineers were interviewed. There were both inexperienced and experienced engineers and both from the domains of process automation and machine automation. The interview themes were constructed based on

the Core-Task Analysis method and the Järvinen's and Poikela's learning at work process model. As a result the automation engineer's core task and learning at work process were defined. Workshops were utilized when defining the concept of work support and training tool.

Based on this knowledge the concept of Autaki tool was defined and a prototype was developed. The purpose of Autaki is to assist engineers in their daily work and to support them in learning at work. According to the concept definition, Autaki is a databank of knowledge which can flexibly be extended and updated with new information. Autaki supports learning at work by providing tools for both independent and collaborative learning.

There is a need for Autaki kind of tool in automation engineering work as well as in many other design work disciplines. The high requirements of performing work fast and effectively in addition to the aging and retirement of the engineers are threats for engineering companies if they do not prepare themselves into this change in an appropriate way. Essential domain specific tacit knowledge have to be transferred from the experienced engineers to the inexperienced ones. This study offers one way to support this complicated and challenging task.

Tiivistelmä

OUTI RASK: Automaatiosuunnittelijoiden työssäoppimisen tukeminen uusien teknologioiden käyttöönotossa
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Avainsanat: automaatiosuunnittelu, työssäoppiminen, taitotukisovellus, oppimisympäristö, elinikäinen oppiminen

Automaatiotekniikka on tekniikan ala, jonka tarkoitus on automatisoida teollisuuden prosesseja ja koneita. Automaatiosuunnittelijan työn tuloksena syntyy automaatiojärjestelmän ohjaamia autonomisesti toimivia systeemeitä. Nykyään tuotantoprosessit pyritään suunnittelemaan siten, että ne ovat rakenteeltaan mahdollisimman joustavia ja turvallisia. Tämä tekee tarvittavista prosesseista ja koneista monimutkaisia mikä tuo niiden automatisointiin lisää haasteellisuutta. Uudenlaista osaamista ja uudenlaisia työskentelytapoja tarvitaan, jotta automaatiosuunnittelijat selviytyvät jatkuvasti muuttuvista ja kehittyvistä työn vaatimuksista.

Tämän lisensiaatintutkimuksen ydin on automaatiosuunnittelijoiden osaamisen kehittymisessä ja siinä, miten tätä oppimisprosessia voidaan tukea soveltuvilla tietokoneavusteisilla teknologioilla. Automaatiosuunnittelijoiden oppimisprosessi pohjautuu automaatiosuunnittelun perustehtävään, jota tutkimuksessa selvitettiin Perustehtäväanalyysi – menetelmän avulla (katso esim. Norros 2004). Varsinaisen oppimisprosessin malliksi otettiin Järvisen ja Poikelan työssäoppimisen prosessimalli (Järvinen & Poikela 2001). Tämä malli yhdistää kolme tunnettua oppimisen mallia: Kolbin yksilön oppimisen kehän (Kolb 1984), Nonakan ja Takeuchin oppivan organisaation mallin (Nonaka & Takeuchi 1995) sekä Crossanin, Lanen ja Whiten esittelemän 4I-mallin organisaation oppimisen viitekehykselle (Crossan et al. 1999). Tässä tutkimuksessa keskitytään erityisesti yksilön ja ryhmien oppimisen tasoille (Kolb sekä Nonaka ja Takeuchi).

Tutkimusaineiston keräämiseen käytettiin kahta menetelmää: teemahaastateluita ja työpajoja. Työpajoja hyödynnettiin erityisesti Autaki-sovelluksen konseptin ja prototyypin kehittämisessä ja arvioinnissa. Haastatteluita taas käytettiin perustehtävän ja oppimisprosessin määrittämiseen sekä sitä kautta Autaki-konseptin määrittämiseen. 18

automaatiosuunnittelijaa kolmesta suomalaisesta yrityksestä haastateltiin. Haastateltavat olivat eri uransa vaiheissa olevia henkilöitä ja edustivat joko prosessi- tai koneautomaatiosektoria. Haastatteluteemat johdettiin perustehtäväanalyysin sekä Järvisen ja Poikelan oppimisprosessimallin teorioiden avulla. Analyysin tuloksina saatiin kuvaus automaatiosuunnittelijan perustehtävästä ja työssäoppimisen prosessista.

Tähän tietämykseen perustuen kehitettiin Autaki-sovelluksen konsepti ja prototyyppi. Autakin lähtökohtainen tarkoitus on auttaa automaatiosuunnittelijoita heidän jokapäiväisessä työssään. Määritelmän mukaan Autaki on tietopankki, johon voidaan helposti lisätä uutta tietoa. Autaki tarjoaa työkaluja sekä itsenäiseen että kollektiiviseen oppimiseen.

Autakin kaltaiselle työkalulle on tarvetta nykyaikaisissa suunnitteluympäristöissä niin automaatiosuunnittelussa kuin muillakin insinöörialoilla. Suorittamisen kulttuuri vallitsee yrityksissä, mikä pakottaa työntekijät tekemään työnsä aina vaan nopeammin ja tehokkaammin eikä virheille ole sijaa. Myös työvoiman ikääntyminen ja siirtyminen eläkkeelle on vakavasti otettava haaste niin suomalaisissa kuin länsimaisissa yrityksissä yleisemminkin. Paljon kokemusperäistä hiljaista tietoa ja tärkeää osaamista siirtyy näiden eläköitymisten myötä yrityksistä pois. Oleellinen osaaminen pitäisi pystyä ennen eläköitymistä siirtämään vanhemmalta sukupolvelta nuoremmille mahdollisimman tehokkaasti. Tämä tutkimus tarjoaa yhden näkökulman ja tavan tämän tiedon tallentamiseen ja siirtämiseen.

Preface

The study presented in this thesis was carried out at the Department of Automation Science and Engineering at Tampere University of Technology. During the years 2002-2014 I had an opportunity to work in several research projects and explore engineering work in many Finnish companies and discuss with many talented automation engineers. In addition to the result presented in this thesis, I have tested my research methods, results and new ideas of workplace learning with university students at Tampere University of Technology (see e.g. SPub3).

I want to express my gratitude to my supervisor professor Seppo Kuikka and professor Matti Vilkko. Professor Kuikka has supervised my work from the beginning and during the years he has reminded me many times about the significance of my research work. With professor Vilkko we have had many interesting conversations about teaching and I am glad he promised to be my other supervisor.

I wish to thank the professors, colleagues, and the personnel of the Department of Automation Science and Engineering for the inspiring and encouraging work environment. I am thankful to the Automation Software research group; it has been a pleasure to work with you. Especially I want to thank David Hästbacka, Ville Valve, and Topi Judén who participated in the development of Autaki prototype, and Timo Vepsäläinen, Jari Rauhamäki, and Petri Kannisto for all the support and encouragement.

I would like to thank the people from VTT Technical Research Centre of Finland and Aalto School of Electrical Engineering who participated the USVA project in 2004-2007. Especially I wish to thank Teemu Tommila, Paula Savioja, and Leena Salo.

Special thanks belong to Jukka and Tero who have been part of my scientific journey - in turns. Finally I wish to thank my parents, sister, and brother who have supported and encouraged me throughout my whole life to follow my heart and to make my dreams come true.

Lempäälä, 12nd November 2014

Outi Rask

Contents

List of Included Publications

The thesis is based on the following publications referred to as

Pub1: Savioja, P., Salo, L., Laitinen, O., Hästbacka, D., Judén, T., & Valve, V. 2007. *Defining a work support and training tool for automation design engineers*. In the Proceedings of the 12th International Conference on Human-Computer Interaction, Beijing, P.R. China, July 22-27, 2007. Lecture Notes in Computer Science series, vol. 4562, 2007, pp. 174-183.

Pub2: Laitinen, O., Salo, L., Hästbacka, D., Kuikka, S., Tommila, T., Savioja, P., Judén, T., and Valve, V. 2007. *A C ore Task Analysis Based Work Support and Training Tool for Control Engineers*, in the Proceedings for the 10th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems, Seoul, Korea, 4-6 September 2007

Pub3: Hästbacka, D., Laitinen, O., Tommila, T., Kuikka, S. 2007. "*Implementing a Work Support and Training Tool for Control Engineers"*, in the Proceedings for the IEEE Fourth International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS'2007), Dortmund, Germany, September 6-8, 2007

Pub4: Laitinen, O. and Kuikka, S. 2007 *On the competence development of control engineers*, in the Proceedings for the 5th International Conference on Researching Work and Learning, Cape Town, South Africa, 2-5 December 2007

Pub5: Rauhamäki, J., Laitinen, O., Sierla, S., Kuikka, S. 2010 "*The Role of User Guidance in the Industrial Adoption of AUKOTON MDE Approach*", in the Proceedings for the 6th Educators' Symposium: Software Modeling Education at MODELS 2010 (Edusymp 2010), Oslo, Norway, October 3-8, 2010

Pub6: Rask, O., Kuikka, S. 2013 *Work and learning of automation experts in industry*. in the Proceedings for the 8th international Conference on Researching Work and Learning, Stirling, UK

List of Supplementary Publications

SPub1: Rask, O. and Kuikka, S. 2003. *eLearning for batch control.* In the Proceedings for the 6th IFAC Symposium on Advances in Control Education: Preprints (pp. 119-124)

SPub2: Laitinen, O., Pohjanen, L., and Kuikka, S. 2004). *Using Web Based Learning Environments in the Control Education at the Tampere University of Technology*. In the Proceedings for the IFAC's Workshop of Internet Based Control Education. Société de l'Electricité, de l'Electronique et des Technologies de l'Information et de la Communication (SEE), Grenoble, France, September 5-7 2004.

SPub3: Laitinen, O., Kuikka, S., & Alho, P. 2012. *The Automation Engineering Students' Knowledge Development in a Development in a Simulated Work Environment.* In the Proceedings for the Conference on Engineering Education 2012 (p. 194)

List of Abbreviations

AJAX	Asynchronous JavaScript and XML
CTA	Core Task Analysis
DOM	Document Object Model
JCR	Java Content Repository specification
LOM	Learning Object Meta-data
LMS	Learning Management System
ObjectARX	Object based AutoCAD Runtime eXtension
PHP	Hypertext Preprocessor
SCORM	Sharable Content Object Reference Model
SOAP	Simple Object Access Protocol
WSDL	Web Service Description Language
XML	eXtensible Mark-up Language

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1 Introduction

1.1 Background and Motivation

Automation engineering is an engineering discipline the objective of which is to design and implement automated functioning of industrial processes and machines. The output of automation engineering is an autonomously performing system that is controlled by an automation system. The automation system controls an industrial process or machine on various levels, ranging from basic control to the management of production. Making production processes more flexible and safe is a current trend in the industry. This increases the complexity of the processes and machines, and requires adaptability from automation systems. Thus, also new kinds of competencies, knowledge as well as work practices are expected from automation engineers who design automation systems.

I have considered in my thesis automation engineering and design work from the perspective of engineers' knowledge and learning. I have focused my research work on two aspects:

- the theories and practices of learning at work; including learning of individuals, groups and organizations
- knowledge sharing practices with suitable computer supported methods and tools

The importance of *learning at work* will be emphasized. Many of the experienced experts in the various domains of industry are going to retire in the next few years. With them significant amount of tacit knowledge about designing automation solutions disappears. New generations have their own knowledge and potentiality to utilize their knowledge but somehow the essential knowledge of retiring generations should be recorded and made available for the younger generations. Individuals' tacit knowledge should become the knowledge of other individuals, groups and organizations.

Engineering work has similar features to any other work but also special challenges (Heikkilä & Mäkinen 2001; Collin 2002; Collin 2004). The work is constantly changing as technologies and design tools are developing. Hence, automation engineers are required to keep up-to-date with the technological advances of automation and information technology. In addition, new kinds of knowledge, competencies, and work practices are expected from automation engineers.

The *competence development* and the knowledge creation of engineers are important for the *individual engineer* but also for a team (s)he is working with and an employing organization. Adams, Turns, and Atman (Adams et al. 2003) have studied the competence development and learning of engineering students through a reflective practitioner theory. In addition, Robinson, Sparrow, Clegg, and Birdi (Robinson et al. 2005) generated in their study a competence profile for future design engineers. This profile includes 42 competences in six competence groups: personal attributes, project management, cognitive strategies, cognitive abilities, technical ability, and communication (in descending order of criticality). Gerber (Gerber 1998) reminds that learning is a long process which does not stop when an engineer graduates but continues through whole life. He also claims that individual's learning at work is not a simple process and different employees absorb information variously.

Lehesvirta (Lehesvirta 2004) has investigated in her study learning as knowledge creation processes both on individual and collective levels. She found out that conflicts and crises experienced by individuals are starting points for the learning processes of an individual. Another focus on her study is collective learning which is based on individuals' willingness and ability to share what they have experienced and learned.

The learning of teams or groups in general is another important level of learning at work constructing the social community for individuals to collectively increase their own knowledge and competence. Liu and Liu (Liu & Liu 2008) have studied the relationship between individuals' knowledge acquisition sources and the patterns of knowledge sharing behaviours. They found out that most employees share the knowledge they have and acquire new knowledge from their team mates with more pleasure than with others outside the own team. Again, Petre (Petre 2004) describes in her study how the expert engineering teams utilize the method of innovation in their work; she has identified the characteristics which distinguish the highest-performing teams. However, team and group work always includes challenges along with enablers. Kleinsmann and Valkenburg (Kleinsmann & Valkenburg 2008) have studied the barriers and enablers which belong to creating shared understanding in co-design projects.

Salas, Cooke, and Rosen (Salas et al. 2008) have studied teamwork and team performance over the past 50 years. They forecast that future challenges will include reconfigurable, adaptive teams and multicultural influences due to the globalization in industry. Virtual teams are becoming more and more common in engineering work where participants could be located geographically far away from each other (Ferreira et al. 2012; Kauppila et al. 2011). Lin, Standing, and Liu (Lin et al. 2008) have developed in their study an integrated model of factors that contribute to virtual team effectiveness.

Organizational learning is based on the learning of the employees of an organization (Huber 1991). Organizations are like knowledge-creating entities according to Nonaka, Toyama, and Nagata (Nonaka et al. 2000). Khapova, Arthur, and Fliesher (Khapova et al. 2009) have studied different ways how employees can contribute to their employing organization. They find out that employees' career investments improve significantly the learning of an organization even though not every employee contributes to the organization in a similar way. Rus and Lindvall (Rus & Lindvall 2002) have studied software organizations where the main asset is individuals' knowledge, intellectual capital. In addition, Lönnqvist, Kianto and Sillanpää (Lönnqvist et al. 2009) have researched the role of intellectual capital management during organizational change processes.

Knowledge sharing is essential. Xue, Shen, Fan, Li, and Fan (Xue et al. 2012) made a literature review based on well-known academic journals (over the years 2000-2009) in construction management in which they examined for instance the implementations of IT in collaborative design. They claim that among others, web-based technologies and collaborative environment technologies are becoming more popular in the future. When considering suitable forms of learning at work and knowledge sharing environments, the computer supported systems and *web based learning environments* offer many advantages over conventional training; for example, they allow asynchronous learning and private study which are important for employees who have tight schedules with their work (Payne et al. 2009; Dolog et al. 2007; Shen et al. 2008; Teare 1998).

1.2 Research Questions

This study is based on several research projects in which I have considered from different perspectives automation engineers' work in both process automation and machine automation. Focus in this thesis is on the question, what the evolving automation engineering work is like and how it can be supported with technological artefacts. In more detail the research problem can be divided as following:

RQ1: Work and learning of automation engineers:

- What is the automation engineering work like?
- What is the automation design process like and how a team and an organization influence the work of an individual automation engineer?
- With what kind of mechanisms the tacit knowledge of automation experts develops and how this knowledge could be transferred for other engineers?

RQ2: Supporting the work of automation engineers:

- What kind of computer assisted modern learning tools could be useful to improve the competence development and work effectiveness of automation engineers?
- How do modern design theories, software production methods and suitable guidance help the engineers' work?

1.3 Scope of the Thesis

The main focus in this thesis is on the learning at work of automation engineers and on how this learning process can be supported with computer-assisted technologies. The learning process of engineers is based on the knowledge of the core task of automation engineers which is investigated with the help of the Core-Task Analysis method (Norros 2004). The core task of engineering work is refined with the ideas of the process model of learning at work introduced by Järvinen and Poikela (Järvinen & Poikela 2001) which combines three well-known learning theories: individual's experiential learning introduced by Kolb (Kolb 1984), the theory of the knowledge creating company introduced by Nonaka and Takeuchi (Nonaka & Takeuchi 1995), and finally the 4I organizational learning framework introduced by Crossan, Lane, and White (Crossan et al. 1999). In this study the focus is on the levels of individuals' and teams' learning at work.

1.4 Research phases

The research work has continued for several years and I have had a pleasure to work with many automation engineers from various Finnish companies during the time. There are several research projects in which I have had an opportunity to work on my thesis. The phases of my research are following:

Phase 1: Studying the work and learning of process automation engineers

- I utilized Core Task Analysis (Norros 2004) for defining the core task of process automation engineering work (Pub1, Pub2)
- I utilized the process model of learning at work introduced by Järvinen and Poikela (Järvinen & Poikela 2001) for defining the learning process of process automation engineers (Pub3)

Phase 2: Studying the work and learning of machine automation engineers

- I utilized core task analysis for defining the core task of machine automation engineering work (Pub6)
- I utilized process model of learning at work introduced by Järvinen and Poikela for defining the learning process of machine automation engineers (introduced in this thesis)

Phase 3: Studying computer assisted methods and tools for supporting the daily work and learning of automation engineers in industry

- I utilized grounded theory (Corbin & Strauss 1990) and content analysis (Järvinen 2004) to study suitable guidance methods and types (Pub5)

Phase 4: Developing the concept of work support and training tool for automation engineers

- I utilized design science research methods such as constructive research (Järvinen 2004) (Pub2, Pub3)

1.5 Contributions

In this chapter the contributions of the thesis are introduced in respect to the research questions.

RQ1: Work and learning:

- Learning possibilities and obstacles of automation engineering work on the level of an individual, a team, and an organization were studied. Learning possibilities and obstacles were identified. (Pub4, Pub2, Pub1)
- Similarities and differences between two automation domains: process automation and machine automation, were discussed to find out some of the general features of automation engineers' work and learning. (thesis)

- Business processes were defined to manage the possibilities and obstacles in the learning at engineers' work. Business processes were also utilized in describing the essential information of engineering workflows. (Pub6, thesis)
- Transforming automation engineers' tacit knowledge into visible knowledge was considered in this study as automation engineers' competence. (Pub4, Pub6)
- The competence development of automation engineers was studied further by comparing the characteristics and knowledge of engineers with the varying lengths of careers. (Pub4, Pub2)
- An automation engineers' learning at work process was identified. (Pub4, Pub6, thesis)

RQ2: Learning tools:

- To transform tacit knowledge into visible knowledge, several guidance types of design tools were examined. The suitability of guidance was approached from four directions: the socialization, externalization, combination, and internalization of knowledge and information. (Pub5)
- The concept of work support and training tool for automation engineers was defined in this study based on the results of the first research question. The main purposes of the tool are to improve collaborative work in design projects and share information effectively. Supporting engineering workflow control is an essential principle in the design of the tool. The concept was tested with a prototype implementation. (Pub2, Pub3, Pub1)

1.6 Organization of the thesis

Chapter 2 introduces the methodological background of the study presented in this thesis. Learning at work in engineering domains in general is discussed. Learning at work is considered from three viewpoints: an individual, a group or a team, and an organization. Finally, the overview into the computer-assisted tools in learning at work is discussed.

The main results of the study are presented in the following two chapters as given in table 1 below. Chapter 3 focuses on the learning at work and competence development of automation engineers. The core tasks of work in both automation domains (process and machine automation) are introduced. In addition the learning at work is discussed from the perspective of an individual, a group and an organization. Chapter 4 concerns the information flow between engineers and the knowledge sharing of individual engineers and groups of engineers. Finally, chapter 5 introduces the concept of work support and training tool for automation engineers. In addition the developed prototype is introduced.

Table 1. Publications (in the order of importance) responding to the research questions of study and the content of the thesis.

Research Questions	Publications	Thesis Chapters
RQ1: Work and learning	Pub4, pub6, pub2, pub5, and pub1	3
RQ2: Learning tools	Pub2, pub3 and pub1	4

2 Methodological Background

Learning at work is a wide study area. Researchers all over the world have studied work and workplace learning trying to figure out how employees, teams and organizations learn and how their competence develops. Several perspectives can be found. Tynjälä presents in her review study (Tynjälä 2008) four interesting perspectives into workplace learning. Firstly, she states that learning can be described at different levels: individual, network, and region. This division has similarities with the division based on Järvinen's and Poikela's process model of learning at work (Järvinen & Poikela 2001) which I have utilized in my study. Another interesting perspective Tynjälä presents in her review considers the differences in how workplaces support learning. There are significant differences between organizations in how they support their employees learning at work and how they utilize the tacit knowledge their experienced employees have (Nonaka & Takeuchi 1995; Nonaka & Konno 1998).

Tacit knowledge is essential when discussing the learning of individual employees, the learning of teams or groups, and the learning of organizations or communities. Many researchers have studied this phenomenon from several perspectives. First the tacit knowledge and tacit skills of an expert should be recognized (see e.g. Evans&Kersh 2004). After that the knowledge is shared by externalizing it (Nonaka & Takeuchi 1995; Sanderson 2001; Osterloh & Frey 2000; Analoui et al. 2014).

In addition to tacit knowledge, knowledge and knowledge management (KM) are important keywords when discussing the learning of individuals, groups, and organizations. Alavi and Leidner (Alavi & Leidner 2001) state that knowledge as a notion has been used since the classical Greek era; nowadays the meaning of knowledge is treated more or less as a significant organizational resource. Ahmed and Wallace (Ahmed & Wallace 2004) have analysed the interactions between novices and experienced engineering designers in the aerospace industry. They find out that it can be difficult for novice engineers to formulate their questions. This indicates the immatureness of novice engineers' knowledge.

Collaborative learning and collaborative work are essential concepts when discussing learning at work. These notions are linked with sharing knowledge or tacit knowledge (Nonaka & Takeuchi 1995). Dillenbourg (Dillenbourg 1999) determines the concept of collaborative learning roughly as a situation in which group of individuals learn something together. This definition is suitable for my purposes. The concept of collaborative work can be seen as a modern form of working in teams or virtual teams. Collaborating is attached in literature to the teams or virtual teams which communicate with computer-supported tools such as email and social media (Powell et al. 2004; Wellman et al. 1996).

The various lines of work have both similarities and differences. Heikkilä and Mäkinen (Heikkilä & Mäkinen 2001) have studied different workplaces: a department store, a metal company, a new media company, and a nursing home. They found out that despite similarities, each workplace and domain have their individual features. Engineering work is challenging in many ways and has its individual characteristic due to, for example, the changing and developing technologies and varying customer projects. Ley, Kump and Albert (Ley et al. 2010) have studied requirement engineering work. Menzel, Aaltio and Ulijn (Menzel et al. 2007) state that engineers are more like the managers of marketing and innovative product development inside organizations since there is a need for engineers to cooperate well with other fields of expertise such as marketing, research and development (R&D) but also with customers, service providers, and external suppliers.

Collin (Collin 2002; Collin 2004) has studied in her doctoral thesis development engineers' and product developers' learning at work. She finds out that there are six categories of descriptions the engineers have as their conceptions of learning at work: learning through doing the work itself, learning through co-operation and interaction with colleagues, learning through the evaluation of work experience, learning through taking over something new, learning through formal education and learning from extra work contexts. These results are in line with my own results from the studies of the automation engineers' conceptions of learning at work.

2.1 Core Task Analysis

Norros with her research group have developed Core Task Analysis (CTA) framework which is useful in determining the construction of the work activity and work demands in complex, dynamic and uncertain environments (Norros 2004; Norros & Nuutinen 2002). With CTA the core task of a certain work is identifiable. Core task is the soul or essence of work which is the same in all situations; it is independent of the organizations of the work or the specific tools being used.

The CTA method has been utilized before this study for example, in studying work in nuclear power plant operation (Savioja & Norros 2004), clinical anaesthesia (Norros & Klemola 2005), and chip manoeuvring (Nuutinen & Norros 2009). The framework is based on several theoretical approaches such as the cultural-historical theory of activity (Engeström 1987; Engeström 1999; Leont'ev 1978; Vygotsky), the functionally oriented cognitive task analysis tradition (Rasmussen 1986; Vicente 1999), and the ethno methodologically oriented approaches for practice (Suchman 1987; Hutchins 1995).

The activity system model (see figure 1) helps, for example, in identifying the object and the objectives of work. The objectives reflect the relationship between the object and the outcome of work. For instance, in process industries the operators work on the process (the object) to produce end products such as paper (the outcome). Thus the objective of work is to use the process to produce paper. The core task is something more than the activities of work; also the restrictions and constraints on fulfilling the core task must be analyzed. For example the safety of the process and personnel must be included in the analysis of paper production work.

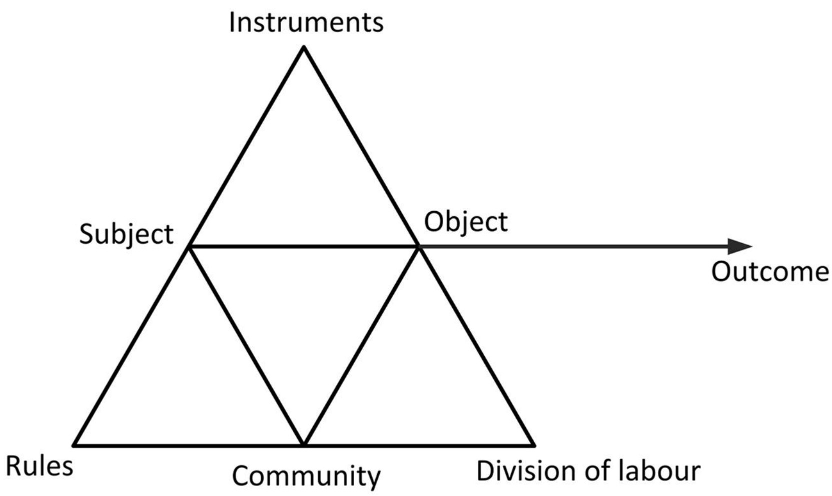

Figure 1. Activity system model. (Engeström 1999)

2.2 Learning at Work on Three Levels: Individual, Group, and Organization

Järvinen and Poikela (Järvinen & Poikela 2001) like Tynjälä (Tynjälä 2008) present in their studies workplace learning as a multi-layered process. Tynjälä has divided workplace learners to individuals, groups, and communities of practice, organizations, networks and regions. Järvinen and Poikela have focused in their approach on three levels; an individual, a group and an organization. Järvinen and Poikela base their approach on three well-known studies as shown in figure 2 below.

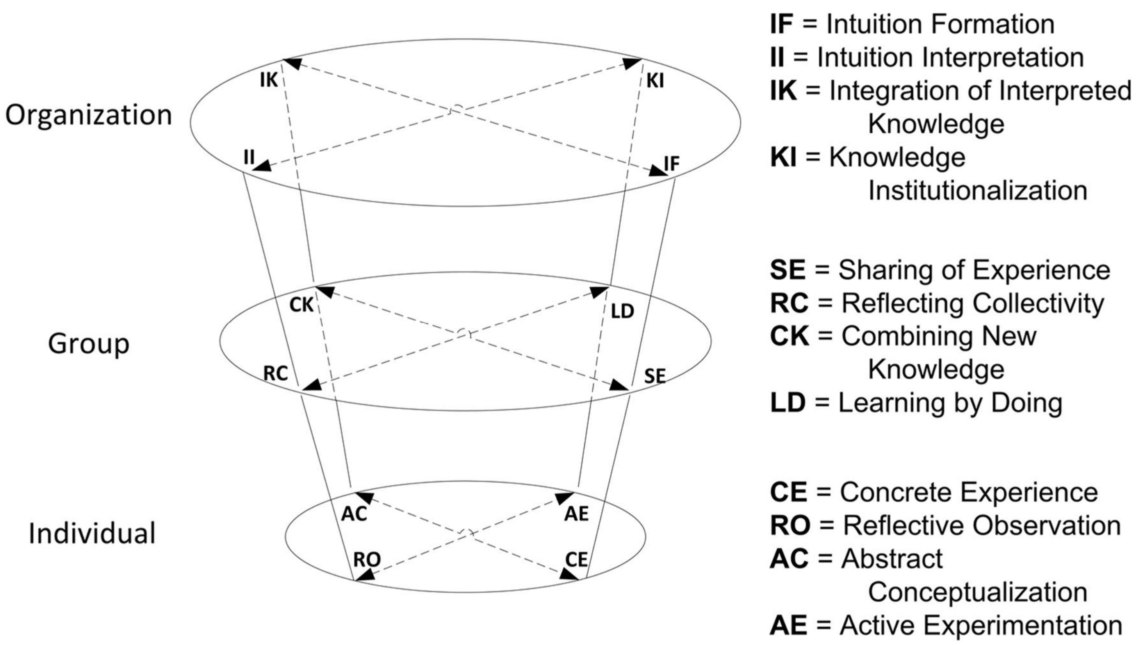

Figure 2. The process model of learning at work introduced by Järvinen and Poikela (Järvinen & Poikela 2001).

In the level of individuals they have referred to the Kolb's ideas of experiential learning (Kolb 1984). According to Kolb, the experiential learning process constructs of structural dimensions such as concrete experience, reflective observation, abstract conceptualization, and active experimentation (see figure 3). Kolb has also described four basic knowledge forms. When reflective observation displaces concrete experience, divergent knowledge is occurring. After that when abstract conceptualization displaces the reflective observation, assimilative knowledge is occurring. Respectively when active experimentation displaces the abstract conceptualization, convergent knowledge is occurring. And finally, when new concrete experience displaces the active experimentation, accommodative knowledge is occurring. According to Kolb, these four types of knowledge become the building blocks for the higher levels of knowing.

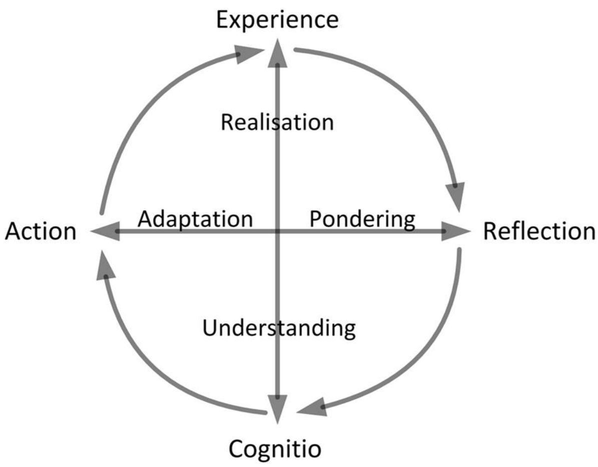

Figure 3. Model of experiential learning. (Kolb 1984)

Like the Kolb's model, the Nonaka and Takeuchi's model (Nonaka & Takeuchi 1995) is based on four phases with which the learning of a group of individuals takes place: socialization, externalization, combination, and internalization. Nonaka and Takeuchi have illustrated in their model how the tacit knowledge of an individual becomes the explicit knowledge of a group and finally of an organization. Through sharing of experience in a socialization phase the tacit knowledge of an individual becomes the sympathized knowledge of another individual. This new knowledge is usually also tacit knowledge. After that, through reflective collectivism in an externalization phase the tacit knowledge of the individual becomes conceptual knowledge, which is explicit. The conceptual knowledge becomes systemic knowledge through combining new knowledge for example with earlier knowledge, and thus new explicit knowledge has arisen. Finally, when an individual uses the new knowledge for instance in his work new tacit knowledge is arisen in the form of operational knowledge.

On the organizational level Järvinen and Poikela have utilized the 4I organizational learning framework introduced by Crossan, Lane and White (Crossan et al. 1999). The framework consists of four processes such as intuiting, interpreting, integrating, and institutionalizing. These processes link together individuals, groups and an organization, and thus, bind together the whole learning at work process presented by Järvinen and Poikela.

2.3 Supporting learning at work

For supporting learning at work processes in the levels of individuals, groups, and organizations, many forms of tools are utilized. Face-to-face discussion is a traditional way to communicate with colleagues. It is effective and recommended in many cases but sometimes it is not enough or even possible. When people are located geographically far away from each other or when the organization is too big to meet all colleagues who can provide help, various kinds of supporting methods and tools have to be developed. Examples of these are for instance different kinds of guidance (Billett 2000; Kim 2010; Suthers & Hundhausen 2003) and design patterns (Carroll & Farooq 2007) which help to re-use good designs.

When designing and developing computer-assisted support tools, there are several alternative technological approaches which can be utilized, such as the object-oriented approach (Parsons 1998; Jagodzinski et al. 2000; Dolog et al. 2007), the model-driven approach (Vepsäläinen & Kuikka 2014; Dolog et al. 2007; Ceri et al. 2007), the ontology-based or the semantic approach (Hästbacka & Kuikka 2013; Hästbacka & Kuikka 2012a; Dolog et al. 2007), or the agent based approach (Yang & Wu 2008). In addition to the technological approaches there are qualitative research methods utilized to define the requirements for support tools (Ball & Ormerod 2000).

Yang and Wu (Yang & Wu 2008) have studied the knowledge sharing in an organization utilizing a special support tool. They have used agent-based technology to develop the tool. Gopsill, McAlpine, and Hicks (Gopsill et al. 2013) have studied with a literature review the suitability of social media for supporting engineering design communication and developed a social media framework to support engineering design. Their social media framework for engineering design communication (EDC) consists of three components; 1) a communication process, 2) an EDC classification and 3) stage-by-stage descriptions of the functionality, and the data and information requirements for a social media tool. They find out that even though e-mail is currently the most common way to communicate (like many other computer-mediated communication tools) it does not possess the capability to effectively support the engineering work. There is, however, a lot of potentiality in it. They conclude that it should be able to provide a representation of the artefact that the communication pertains to, capture the engineering context related to the discussion, enable diversified discussion opportunity, and finally, ensure the relevant experts are aware of the right communications.

Parsons (Parsons 1998; Jagodzinski et al. 2000) has studied the electronics engineering design teams in industry. Based on this study he has developed a prototypical computer-based support tool for project leaders and design engineers. The prototype is developed with object-oriented software development method.

Kauppila, Rajala, and Jyrämä (Kauppila et al. 2011) have studied knowledge sharing through virtual teams with an intranet portal which was open to all employees of a company. The portal consists of a communication space for informal discussions and search functions to retrieve previous discussions and comments, and additionally, for instance, current product materials, brochures, and product manuals.

Finger, Gelman, Fay, Szczerban, Smailagic, and Siewiorek (Finger et al. 2006) have studied collaborative learning both in student design teams and professional design teams. For this purpose they have developed a computer environment which supports the activities of group collaboration. For tool development they utilized a user-centred design process approach which had two development iterations. In the tool, members can contribute to the content focusing on discussion that surrounds the artifacts or information from separate team members or other teams.

Ball and Ormerod (Ball & Ormerod 2000) have utilized in their study applied ethnography to the design of a computer-based design support tool. To find out how designers re-use earlier design knowledge, they used observations. Based on the results of ethnographical study, they developed a design support tool prototype utilizing object-oriented approach. As a result, they argue that the method of ethnography is a powerful tool to determine software applications such as a design support tool.

3 Learning at Work of Automation Engineers

3.1 Research frame

Three Finnish automation design companies participated in the study (see figure 4). Two of the companies (company A and C) are large and one is a small and medium size (SME) company (company B). Company A develops and uses its own automation system product. Company B, on the other hand, uses several automation products for the implementation of automation systems when functioning as a subcontractor in automation projects. Both of these companies are working in the domain of process automation. The company C produces large moving work machines for which they produce automation solutions. All three companies can be characterized to fit Petre's (Petre 2004) norm of successful innovative design companies. They are in close contact with research institutes, work in small multidisciplinary project teams, and are familiar with the technology front end.

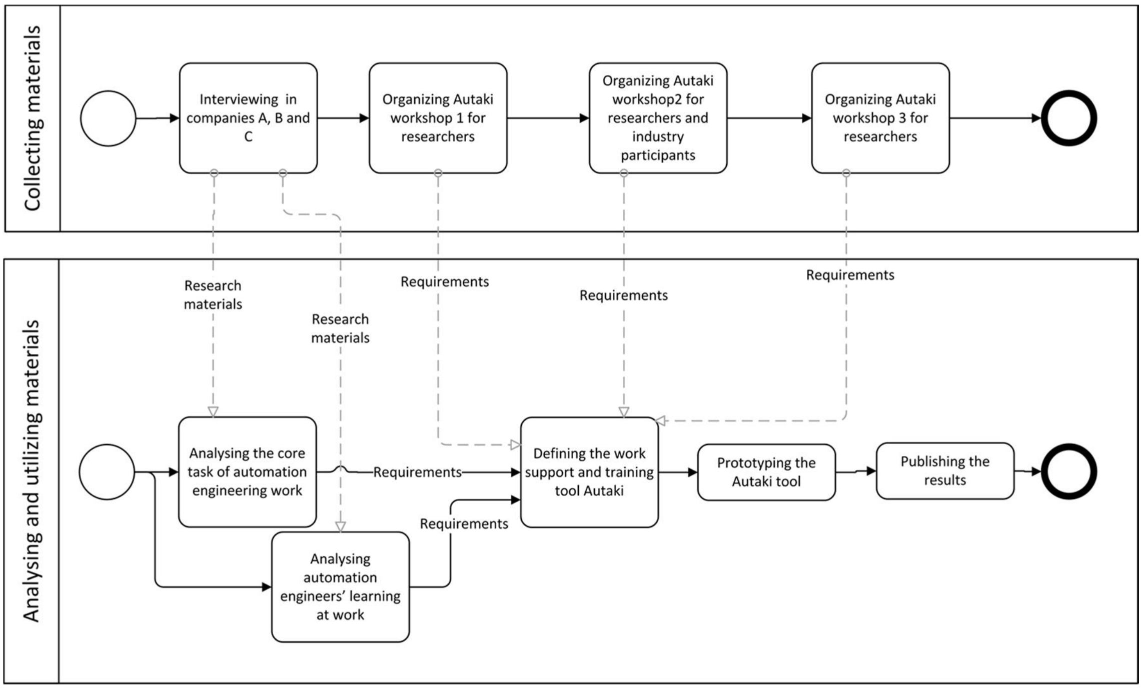

Figure 4. Research frame.

Research material was collected with two methods: workshops and semi-structured interviews (see figure 4). Workshops were utilized when defining the concept of a work support and training tool and they are introduced more precisely in the chapter 4. The study of engineers' work and learning at work was carried out with interviews: altogether 18 automation engineers were interviewed. There were both inexperienced and experienced engineers. The interview themes were constructed based on the core-task analysis methodology (Norros 2004) and the learning at work process model (Järvinen & Poikela 2001). In addition, Sandberg's (Sandberg 2000) study of engineer's conceptions of work was utilized as an inspiration when designing the interview themes. The interview themes were:

- the core task and the requirements of automation engineering work
- the objective of automation engineering work
- the construction of the work activity
- the criteria by which the output of work is evaluated
- the factors that influence the success of work (such as tools, for example)
- information, collaboration, and work practices
- the skills and knowledge possessed by a competent automation engineer
- possibilities and obstacles for learning

All the interviews were audio recorded and transcriptions were made of the audio data. All the transcriptions were collected to an analyzing environment (Atlas.ti) so that the individual answers could be compared and classified.

In the analysis of the results it was discovered what the automation engineers considered as the objective in their work and what those features are which make a good automation engineer. The activity system model (Engeström 1999) was constructed by the interview data.

3.2 Core task of automation engineering

The model of the core task is defined by analyzing the objective of work and the means that the personnel have to fulfil the objectives. Based on that, the activity system model is constructed as one part of the core task analysis (see figure 5). Essential concepts in the model are *the object of work, the objective of work*, and *the tools and techniques* used to operate on the object. The objective of work reflects the relationship between the object of the work and the outcome of work.

In automation engineering engineers (the subjects) work on automation applications (the object of work) to produce an end product, i.e. a complete automation system (the outcome of work). Tools and techniques, such as PLC or DCS software with which the automation applications are implemented, are used to operate the object. The engineers collaborate within the team as well as with other project stakeholders. The division of duties is based on project phases and disciplines, and the work is guided by instructions such as standards and regulations, and organizational work practices and written internal guidance.

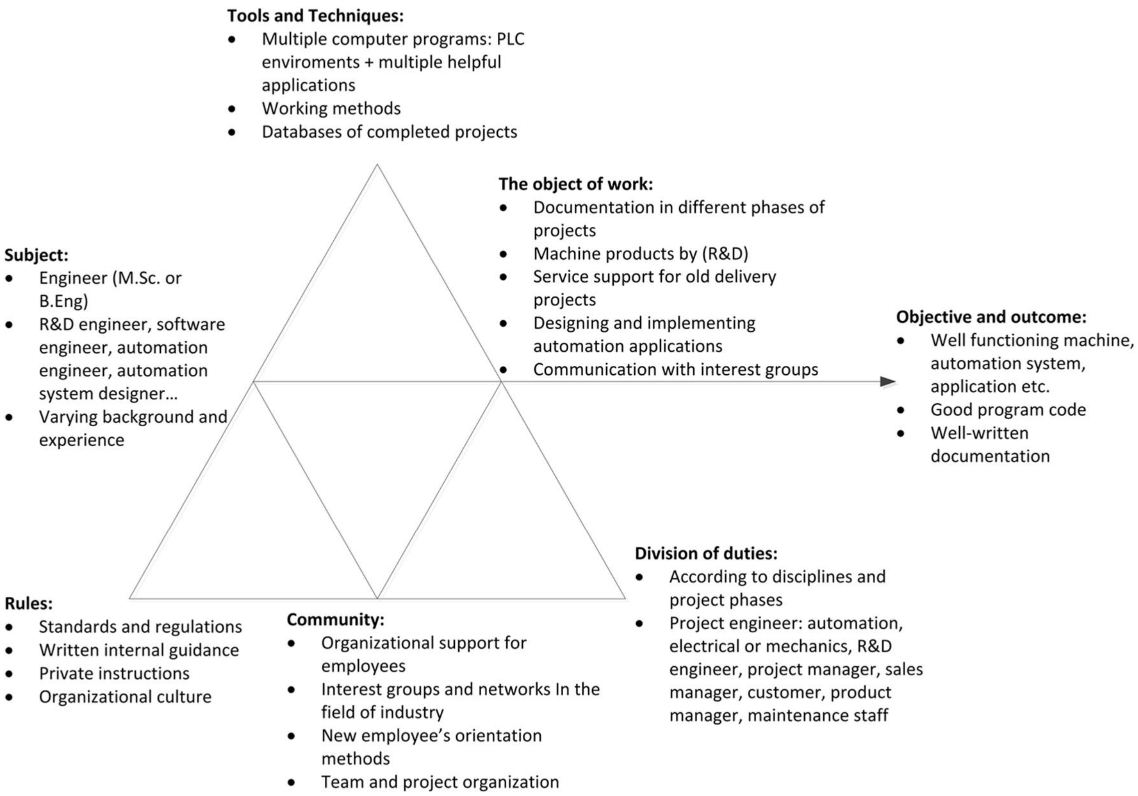

Figure 5. The automation engineering work described as an activity system model (Engeström 1999).

The automation engineers do not fully share the conception of what is the objective in engineering design. There are engineers who see a satisfied customer as a successful output. Some of the other engineers emphasize that also the application must work correctly in all conditions despite what the customer might consider good enough functioning. In addition, some engineers extend the objective to cover the development of own work methods and techniques and also the fact that the code must not only work but also be legible and understandable by other engineers. Also product development was seen as a goal of work.

There were also different conceptions of the object of work. For example when asking what happens in automation engineering, the answers varied from “automation of an individual piece of equipment” and “changing information from one format to another” to “implementing correct functioning of an industrial plant”. This shows that some automation engineers think of the role of automation as more vital in the whole engineering project than others.

The differences in the conceptions can be explained by the following factors:

- Educational background
- Years of experience in the work
- Type of work carried out during the career so far
- Factors related to work culture

The division of conceptions indicates that individual engineers have different abilities to see the completeness of their work. This is so especially in large automation projects in which one engineer works on a relatively small piece of the entire automation system. In small projects in which there is one or two automation engineers responsible for the implementation of an entire automation system the engineers understand better the meaning of their work as a part of the whole.

In addition, there are often contradictory objectives in the work that create tensions and lay demands on the engineers as workers. For example, safety and cost efficiency are often both considered objectives of process automation engineering work (in addition to actual production). This means that work practices which help people cope with the demands must be created and maintained.

The engineers’ actions when facing difficulties or problems in the work were studied when recognizing their work practices. Some turn to colleagues to get help; others use literal sources to find answers to questions. Often in a project or in a company there are some persons who are experienced and whom many other engineers use as an information source in problem situations. Especially the inexperienced engineers who work in large projects claimed that they wanted to carry out some pre-research before turning to an experienced engineer for answers as they wanted not to “waste his valuable time”. Asking help from colleagues seems to be easier when automation organization and automation projects are small.

According to the interviewees, it can be difficult to find the information one is looking for although there is a lot of information available in databases and other information sources within and outside the organization. There are at least two reasons for the difficulties in finding information: firstly, the information retrieval functionalities of the information sources are not good enough; and secondly, the person seeking for information does not know the problem domain well enough to formulate questions correctly. Because of the problems in using databases and other information sources it is often easier to ask colleagues for help.

When implementing technical solutions according to the preliminary designs the automation engineers have to decide how to implement each automation application. Often it is beneficial, in terms of efficiency and quality, to reuse solutions that have been implemented in previous projects, and thus have been proofed to be working well. According to the interviews, the ratio of how much control engineers have to implement novel solutions and how much they can exploit existing designs is dependent on the field of industry.

One of the characteristics of the automation engineering work is that it is carried out in an engineering middle field. This means that the automation engineers have to gather information from all other fields of engineering, e.g. process, chemical, piping, and electrical; and with this knowledge interpret the intended functioning of the plant. This calls for good cooperation and communication skills from automation engineers. They also have to know the “languages” of the other domains in addition to their own to avoid misunderstandings. Often the automation engineer has to start designing automation before the other disciplines are ready with e.g. process design. Usually, even the customer’s requirements are not yet complete. This means that the automation engineer must work with uncertain information. When asked about the characteristics of a good automation design engineer a few of the interviewees answered that one has to know what can already be decided about automation – even though the requirements for automation are not complete.

Table 2. Comparing machine and process automation engineers' work.

Machine automation engineering	Process automation engineering
The field of industry is rather insignificant when designing automation for a machine. The machine could be a part of a larger entity, such as a process.	The field of industry guides the design work of the process automation system.
One engineer is responsible for the entire automation application.	An automation project is usually divided into smaller parts, i.e. according to the project phases. Several automation engineers share these parts.
Control applications are usually rather small and relatively simple.	Control applications can be rather large and complicated.
The core team consists of an automation engineer, an electrical engineer and a mechanical engineer.	The core team consists of many automation engineers. Process and electricity are designed separately.
Both machine automation engineers and research and development engineers considered the main object of a work to be a well-functioning machine.	The engineers' impressions of the object vary from "automation of individual equipment" and "changing information from one format to another" to "implementing correct functioning of an industrial plant".
Problems are solved usually by asking help from colleagues. Research and development engineers also utilize literature, the data sheets of devices etc.	Problems are solved by asking colleagues for help and finding answers from literature, old projects etc.
Novice machine automation engineers are sent to commissioning as soon as possible; commissioning is the best place to learn how the machines work. Also novice research and development engineers have opportunities to see machines on site.	Commissioning is considered to be the best place to learn how the process works but there are seldom financial or scheduled opportunities to send engineers to the customers' site.

Core-task analysis aims at recognizing the core content of a particular task. A core task can be expressed as core-task demands, the coping with which signifies success in work. Core-task demands identified in this study to characterize the work of automation design engineers can be summarized as:

- Adaptation to the technology change, maintaining and gaining technical skills
- Cooperation and communication with different engineering disciplines
- Working with uncertain information

Both domains of automation considered in this study have similarities and differences as described earlier in this chapter. The similarities and differences are collected in the table 2 as a summary.

3.3 Automation Engineers' Learning at Work

The automation engineering work is constantly changing because of the constantly developing information technology. This creates learning requirements for all the engineers independently of their previous experience. This learning at work is mainly informal learning but there are also features of formal learning due to the training and courses organized by external educators.

3.3.1 Informal learning in automation engineering

Companies can support competence development and engineers' learning at work in many informal ways. For instance, a new employee usually works with a more experienced engineer for some time. In addition, locating engineers working in the same project close to each other helps communication between them. Furthermore, collecting feedback from clients and reviewing finished projects with the project team, as well as participating in commissioning, are ways to increase professional competence.

One example of informal learning of automation engineers takes place when working on an assignment. In working on an assignment an engineer needs information and knowledge. Some of the knowledge he already has as his competence but there is a lot of information and knowledge, such as customer's requirements, that he does not know beforehand. I have defined one common automation engineers' process of working on an assignment. This process is introduced in the figure 6.

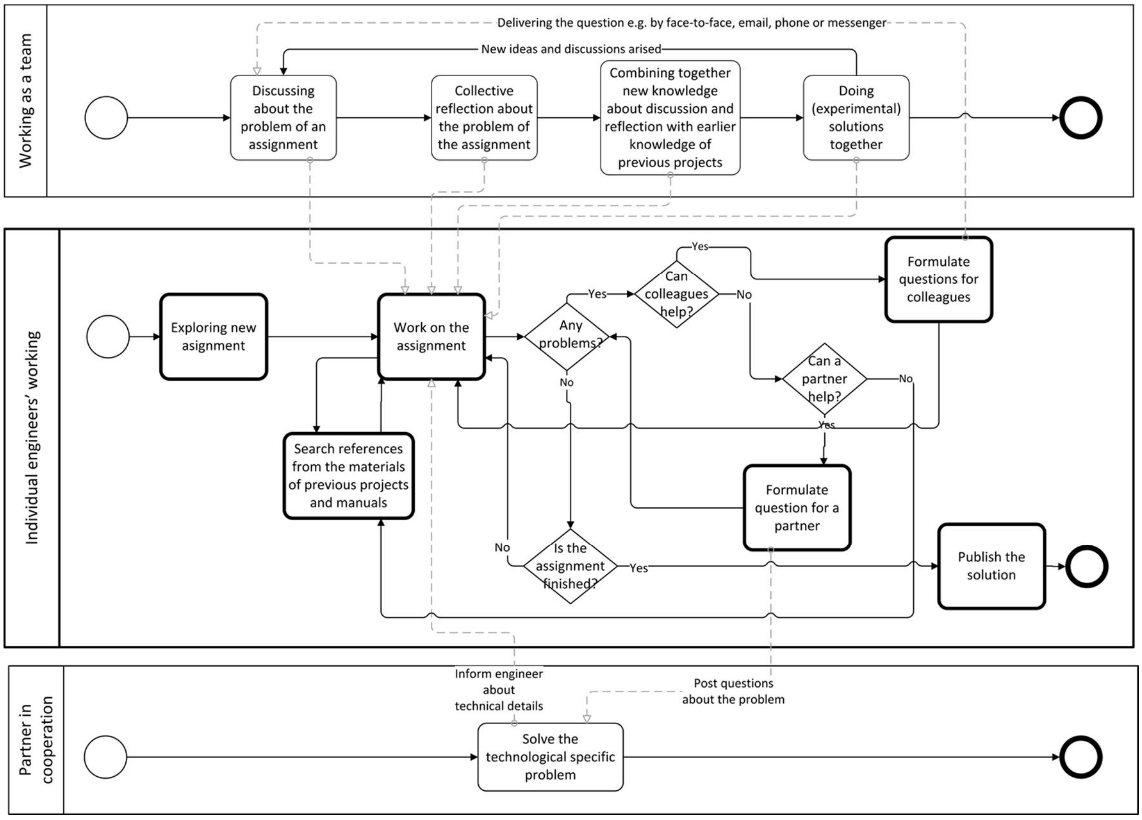

Figure 6. Working on a work assignment from an individual engineer's point of view.

Comparing this process to the Kolb's experiential learning circle (see figure 3 and (Kolb 1984) we can see similarities especially in the "individual engineer's working" pool. There are several circles during which the first experience of a new task through analysis of its content with reflection of own knowledge, and through understanding the task more and more precisely converts into the final automation solution which is well-functioning and tested. In an example presented in table 3 one idea of this spiral of individuals, learning is illustrated. After all, this picture gives us some idea how the learning at work of automation engineers occurs and how they solve problems. In real world this circle is almost endless due to the lifecycle of the project including integration testing and commissioning of the automation system during which there occurs more improvement needs for the parts of the system. Thus, it is reasonable that when asked to describe their professional learning experiences, engineers said that the implementation of the application in the field, at the real plant, was the most important learning experience.

Table 3. One example of the learning circles of an individual automation engineer.

Circle #	Experience	Reflection	Cognition	Action
Introducing	An engineer has first documents and gets an idea what is expected. *Then…*	…the engineer tries to figure out does he know enough about the task or does he need to achieve new knowledge to solve it. *After that…*	…he studies essential new knowledge and forms a potential solution method with the knowledge he has. *And after that…*	…he makes the very first version of the application *But…*
Hard working (several circles)	…he realizes that there is a feature in the description of the application he did not see in the last time. *So…*	…he reflects more and achieves necessary new knowledge. *And then…*	…he refines his idea of the potential solution method, *and…*	…he improves his application. *Until…* *Finally…*
Finishing	…the engineer finds out the last missing feature he has time to solve, *and…*	…he finds out does he need new knowledge to solve it. *After that…*	…he refines last time his idea of the solution method, *and…*	…makes last improvements to the application before he releases it.

The previous example indicates that learning occurs all the time when an automation engineer is working. Every project is different due to, for example, different requirements of a customer, automated equipment (process, machine…), and operational environment. The engineer's competence develops inevitably when he goes through one project after another. Most of this knowledge is invisible, so called tacit knowledge which is a part of the engineer's individual human capital (Lönnqvist et al. 2009).

Table 4. Features how an experienced automation engineer works versus an inexperienced one (according to the interviews).

Experienced automation engineer	**Inexperienced automation engineer**
Does his work with self-confidence. Performs work tasks routinely.	Ponders different solutions for each work task and is uncertain which solution is the best one.
Performs his work effectively; does less work because knows the minefields of development environments.	Needs time to implement applications e.g. because does not know all features of the development environments. Needs time to learn to use new tools.
Knows which structure is best for an application he is working with due to the experience of earlier projects.	Might make mistakes in the structure of an application due to lack of routine. Needs to be more careful than experienced engineers to avoid mistakes.
Adopts new programming environments effectively because he recognizes the similarities with other similar tools.	Adopting new programming environments could take time when the engineer has no earlier experience on similar tools.
Has seen several machines and knows how they function and how they should function. Also understand the constraints caused by the materials of the machine.	Does not know much about the machines or the properties of the manufacturing materials.
Knows the circumstances an environment poses for an automation application and a machine.	Does not understand the circumstances on the site.
Easily sticks into the routines and does not adopt new skills which harm e.g. innovativeness.	Is usually eager to try new methods in his/her work.

I compared experienced automation engineers to inexperienced ones trying to prove the competence development (see table 4). I asked the interviewees how experienced engineers work differently than inexperienced. According to the interviewees, competent automation engineers have several characteristics. For example, they have to know and understand the physical target of their work such as the process, machine, or a piece of equipment they are automating. When they know the physical target well, they can more easily supplement the weaknesses of the design specifications such as diagrams and user requirements. It is also important that engineers can see the whole design project as the object of work. In addition, competent engineers recognize which tasks are important at each stage of the project, and they can separate trivial tasks from difficult ones and implement them in an appropriate order.

3.3.2 Formal learning in automation engineering

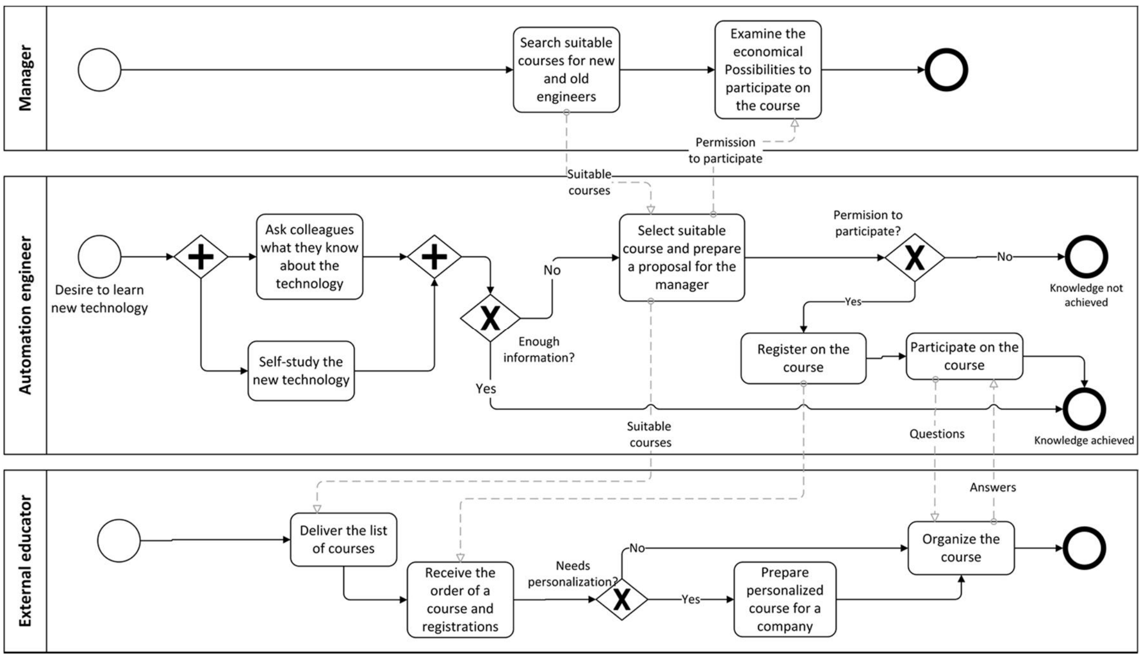

Figure 7. Process to how the engineers go to courses.

One example of formal learning at work occurs when engineers take a course (see figure 7). Training was mentioned as a further demand for competence development, in particular courses that are tailored only for the company. Especially inexperienced control engineers wanted more courses, but also more experienced engineers need some training – at least when they work with a new technology or tool. But training is usually quite expensive and it does not create business profit immediately, and thus the funding could be hard to find in small and medium-sized design companies. Employees seem to participate in training if it is necessary from the beginning project's point of view. Large companies usually have more resources, so this problem is not so acute there. In any case, one probable reason (in all types of companies) for engineers not to participate in training is as simple as lack of time. Nevertheless, the engineer's own activity was essential in all companies to enable one to take a course.

3.3.3 Learning by Collaborating in Teams

The importance of sharing knowledge between team members and other stakeholders is emphasized in individual automation engineer's work. One example of potential collaboration during design project is described in figure 9 which extends the example of individual's learning (figure 8) into the learning of a group. In the example in figure 9 the individual engineer's role as a team member is used to describe the development of team learning. Large automation system consists of small pieces implemented by individual engineers. The competence of the team consists of the competence of its individuals, and thus, their knowledge and ability to learn.

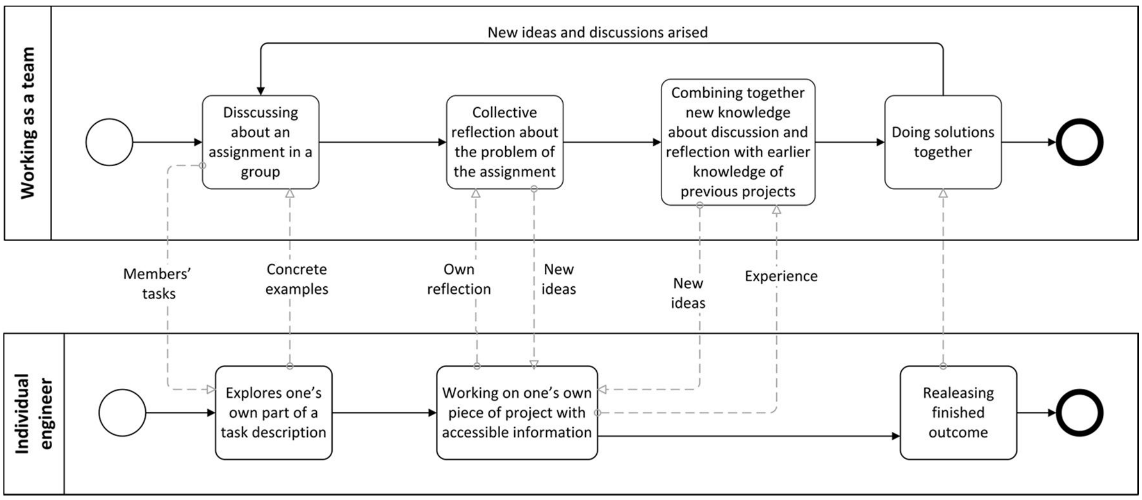

Figure 8. Collaborative learning in teams and individual's role in it.

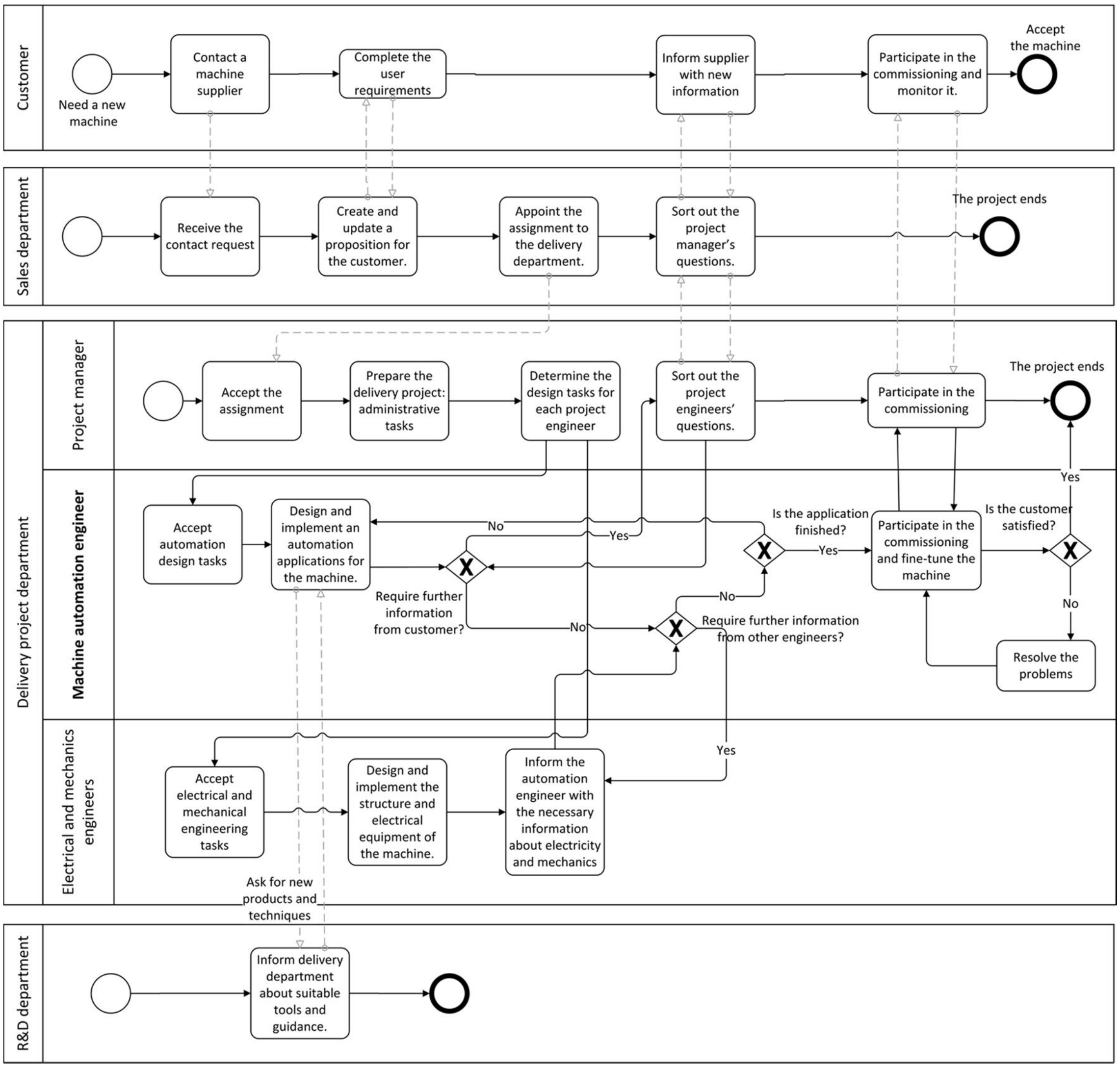

Figure 9. An example of the main information flows in a delivery project in one the companies participated this study. Other ones have similarities with this even though there are also some differences.

When considering the team as a larger group of stakeholders than automation engineers, the learning through collaboration can be something similar to the example presented in figure 9. When considering this flowchart from the learning perspective, this has features both from the learning of teams and the learning of an organization.

4 The Concept of a Work Support and Training Tool

4.1 Defining the work support and training tool

The defining of a work support and training tool Autaki was carried out with three workshops and interviews. The first version of the model was validated in a workshop with the participating companies A and B when defining the user requirements of Autaki tool: knowledge about automation engineering work was utilized when defining functional and non-functional requirements for the concept of work support and training tool. This part of research work is discussed more precisely in included publications Pub2, Pub3, Pub1, and Pub4.

Along with interviews, three workshops were organized. In these workshops the results of the interviews were discussed and requirements for Autaki-tool were defined. Autaki concept introduces ideas of how this kind of computer supported tool can help the automation engineers' daily work and promote their professional competence development. (Pub4, Pub1, Pub2)

Two of the workshops were organized for researchers only and in one of the workshops both researchers and industrial representatives from participating companies A and B took part. In defining requirements different kinds of methods such as brainstorming and role play were used. From the initial requirements specification a subset was selected to be implemented in the Autaki prototype. The selection of the requirements was done in cooperation with the participating companies. (Pub2 and Pub1)

In the first workshop general features of the application were outlined mainly using a brainstorming method. After brainstorming the formulation of the requirement specification of work support and training tool Autaki was started. When finishing the first version of the requirement specification, a second workshop was organized. In this workshop company participants' opinions of the requirements of the tool were discussed and the requirements specification was refined. The purpose of the last workshop was to verify the requirements specification before releasing it with researchers. A role play method was used in the third workshop. The roles were hypothetical Autaki users such as a senior engineer, an automation engineer, and the administrator of Autaki application.

Based on the user requirements, more specific design of functions and technical features was started. During this analysis, e.g. the content and the functions of Autaki prototype were determined. After identifying the basic structure and functionalities of the Autaki tool, the architecture of the prototype was designed with a special emphasis on the possibility of future extensions. Implementation techniques were selected using flexibility and novelty as criteria. As new techniques as possible were used to experiment their suitability for this kind of application. Even if immature techniques posed some problems during implementation, this experiment gave developers a lot of useful information and competence. (Pub3 and Pub2)

For defining requirements for the Autaki protype application, the demands of work and the information needs were considered from the perspective of different groups of users and situations of use. Descriptions of scenarios on how, when, and why users would want to use the tool, as well as what kind of information would be needed, were written.

The scenarios illustrated e.g. the following usage situations. In the first situation an inexperienced automation engineer searches for an answer to a technical question considering process measurements. In another situation an engineer wants to comment on a design template while he is implementing an automation application with a design tool. When the engineer has more time in use he can go more deeply into a new subject. In a fourth situation an experienced engineer wants to share his knowledge on project life cycle, for instance, which tasks can be conducted in a situation when part of source information is missing.

4.1.1 The Autaki concept and requirements

The purpose of Autaki is to assist engineers in their daily work and to support them in learning at work. According to the concept definition, Autaki is a databank of knowledge which can flexibly be extended and updated with new information. Autaki supports learning at work by providing tools for both independent and collaborative learning. These issues discussed in this chapter are published in Pub1 and Pub2 more precisely.

Autaki functions as a uniform portal to different kinds of information sources inside and outside the company. Advanced search tools and multiple ways of navigating in the content are provided to ease the search of information. Also, to make the use of Autaki flexible, it can be integrated to design tools. The contents of Autaki can be formed of, for example, the following kinds of information:

- Generic standards and guidelines
- Company's own instructions, policies, and best practices
- Information of Autaki users and their fields of know-how
- Design patterns
- Examples of solutions for various problems
- Descriptions of industrial processes and instruments, domain specific terminology, information of the latest technological advances
- References to information sources outside the company, e.g. web pages of component suppliers
- User's comments related to the contents, questions and answers
- Personal notes and bookmarks of the users

From the point of view of learning, tools for collaboration are important since co-operation with knowledgeable experienced colleagues seems to be important especially for the inexperienced engineers. With Autaki, engineers themselves can add comments to the contents as well as ask and answer questions related to specific topics, and in this way share knowledge in the organization. Learning is most effective when a person tries to reflect new information by himself. For supporting reflective practice, Autaki contains tools for creating personal notes and bookmarks.

The **requirements** of Autaki are summarized below:

- The application supports the daily work of control engineers e.g. by providing information that is useful while performing regular automation tasks
- The application supports learning at work and engineers' competence development
- The application provides methods and tools for collaboration and knowledge sharing
- The application provides methods and tools for updating and adding material easily
- The application provides different views to the content i.e. the content can be assembled into different kinds of entities e.g. handbooks and courses

- The application provides links to related material containing background information
- The application provides advanced search tools and multiple ways of navigating in the content
- The application supports creating personal bookmarks and notes
- The application can be integrated to existing tools and practices

4.2 Prototyping Autaki tool

During the prototype development in 2005-2007, new technologies and their suitability for this type of project were tested. Research to determine the appropriate technological approach was carried out earlier in 2002-2004 when I was working on my Master thesis (Rask 2002). In the master thesis I studied web-based learning environments and the usage of these environments in education at university (Rask 2002; SPub1; SPub2). The aim was to base the application on open source tools and software components as well as flexible technologies. The problem was not the lack of useful tools and technologies but rather a large number of them.

Autaki application corresponds with the requirements by automation engineers in many ways. For example, our group designed an annotation service into the application which engineers can use to give comments and ask questions about materials. All users see all comments and questions, and everyone can comment on someone else's comments and answer the questions someone has asked.

In addition, the content of Autaki has been designed in a way that serves best its purpose. For that reason material was divided in three dimensions: life cycle model, the operational hierarchy of automation and application area. In addition, appropriate contents for all these dimensions were specified.

4.2.1 Autaki architecture

The prototype of Autaki tool is a distributed application that consists of separate client layers, including a *web client* and a *tool client*, and a core service layer in the form of a *content server* (Hastbacka et al. 2007; Laitinen et al. 2007). The architecture is introduced in figure 10. The content server implements the essential core functionality of Autaki, serving as a repository for learning material and cumulative, annotated knowledge. The functionality is divided into services that provide means for accessing content and collaborative knowledge sharing.

Besides the Autaki content server, the prototype consists of a web client application for a web browser interface (Hästbacka 2007) and a tool client interface integrated into an automation design tool (Judén 2007). The client applications can either be simple thin client solutions or more sophisticated rich client applications that offer more complex functionality using the provided lower-level services. Client applications access the content server by sending XML-documents using the SOAP-protocol (Simple Object Access Protocol) (see e.g. Hadley et.al 2003). By using shared XML schema models (see e.g. Fallside & Walmsley 2004) defined in the WSDL documents of the services, the structure of messages can be defined in a standard way without any platform restrictions.

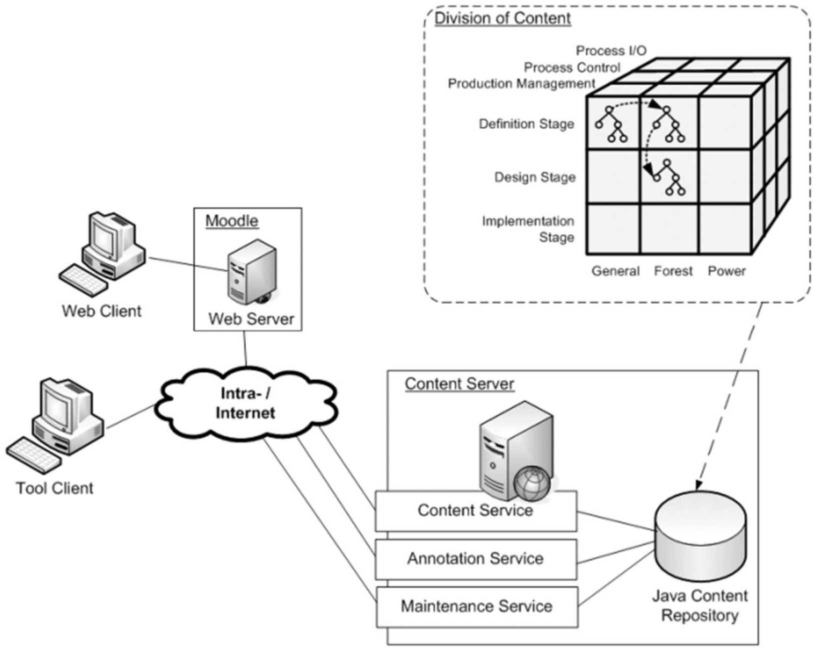

Figure 10. The general architecture of Autaki application. (Pub3)

4.2.2 Autaki content server

The content server is the core of Autaki and serves as a central content repository for the whole Autaki application. In the Autaki prototype the content server offers services for accessing displayable content (*Content service*) and maintaining knowledge in the form of annotations (*Annotation service*).

The Autaki content server is based on an application server running the Apache Axis2 software as a web service platform. The material in the content repository is described according to the IMS Global Learning Consortium specification for Learning Object Meta-data (LOM) (see e.g. IMS Global Learning Consortium 2006). The IMS LOM used in Autaki contains information on object title, a unique identifier, a short description, and keywords. In order to categorize content more effectively the XML-based IMS metadata schemes have been extended with additional fields containing information on lifecycle, industry and automation hierarchy level. The content is then composed into packages complying with the SCORM (Sharable Content Object Reference Model) definition of aggregated educational content (see e.g. Dodds & Thropp 2004, Bohl et.al 2002). SCORM packages standardize content composing and make sharing and the utilization of existing packages possible.

The packages are imported to the content server and built into a JCR (Java Content Repository specification) compliant Apache Jackrabbit repository tree (see e.g. Sommers 2005). The Jackrabbit repository is a multi-purpose node tree for all kind of content and is used by the web service method implementations for effective data access and content maintenance. In the repository the Content service organizes the imported packages into organization and item nodes according to the SCORM specification with IMS LOM information on the nodes.

The Annotation service manages annotations, and the only link between the annotation and the content object is the unique identifier of the specific annotated object. Independent services give client applications more freedom by using only parts of the Autaki core functionality. The same Annotation service can be used, for instance, in conjunction with other types of objects e.g. design objects in integrated design tool clients.

4.2.3 Web client for content server

The web client is a web user interface to the Autaki tool and it can be accessed from anywhere using a standard web browser. In the Autaki prototype the web client offers functionality for content browsing, advanced searching, personal bookmarks and collaborative features such as annotations and discussion forums.

The web client is built as an extension module to the Moodle learning management system (LMS) (see e.g. Cole & Foster 2007, Moodle 2014). Moodle is a famous open source project and the Moodle LMS is used worldwide by schools, universities, and several other institutes for distance learning and online education. By using Moodle as a basis for the web client, the complexity of the client can be reduced and the same Moodle look and feel retained. The functionality of the Autaki module can be used to complete the existing features of the virtual learning environment as the LMS is also getting more popular for corporate use.

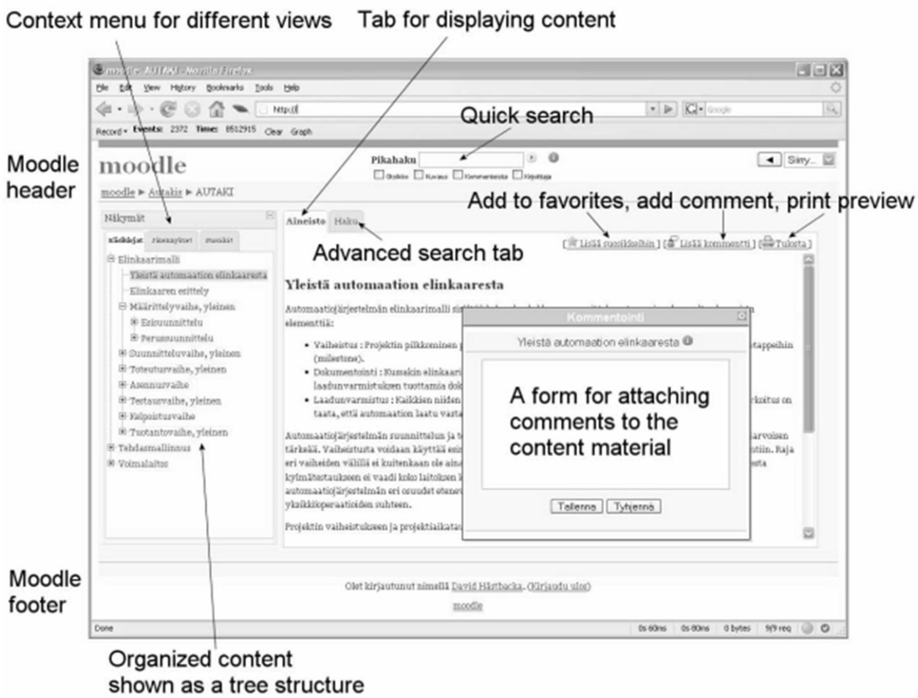

Figure 11. AUTAKI web client user interface. (Hästbacka 2007)

Creating the client application as a Moodle extension results in using PHP (Hypertext Preprocessor) as the client server side technology. The web client user interface also makes substantial use of AJAX (Asynchronous JavaScript and XML) technologies for a richer and more responsive user experience (see e.g. Mahemoff 2006). There are, for instance, no further complete page loads after the application start document has loaded, thus reducing bandwidth consumption and most importantly response times. On user actions JavaScript code within the initial HTML-document is executed in the browser. The JavaScript code makes necessary requests to the web server and displays the returned content by modifying the HTML DOM (Document Object Model) structure on the fly without refreshing the whole page. For Autaki core functionality, such as accessing Autaki content or annotations, the web server makes a SOAP call to the content server, processes the response and modifies it so it can be displayed in a web browser prior to responding to the web browser request.

4.2.4 Tool client for content server

The aim of the tool client is to show the integrability of the Autaki concept and bring the Autaki services closer to everyday design tasks of a control engineer. The main functions in the prototype of the tool client are searching for detailed information and making annotations possible for both content and design objects. Annotations for design objects make the design process more collaborative and enable contextual information regarding the use of certain blocks, elements and good practices.

The design tool used in the prototype was an application programming tool based on AutoCAD. Using the ObjectARX (Object based AutoCAD Runtime eXtension, see e.g. (Judén 2007)) interfaces of AutoCAD the integration was possible without making any changes to the existing design tool. The tool client was implemented on the .NET platform using C# as the programming language. Using web service tools provided by the .NET platform the Autaki content server was easily integrated into the tool client.

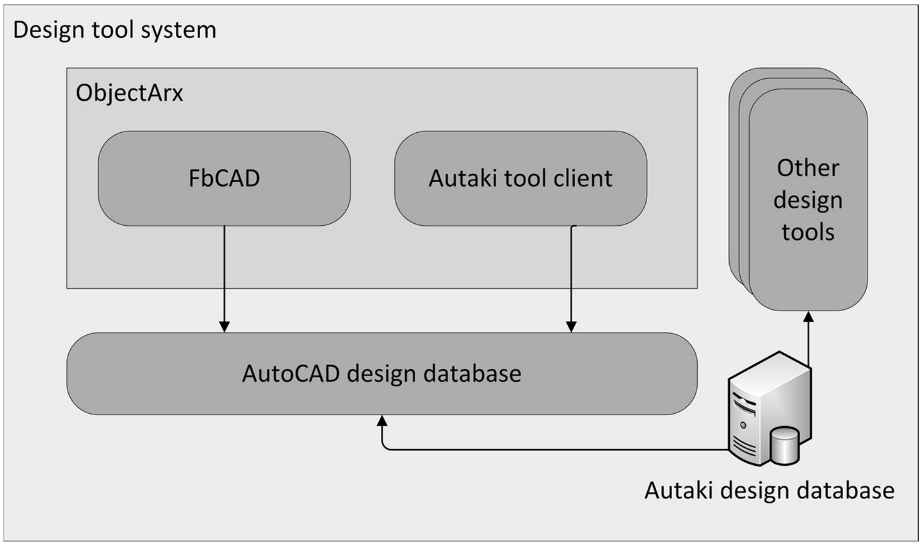

Figure 12. How the tool client communicate with design system. (Judén 2007)

4.2.5 Autaki contents

The contents of Autaki are organized into entities according to several dimensions, such as the field of industry, the life cycle phase of a project, or the hierarchical level of automation functionality (see figure 13). Each entity consists of information components forming a tree-like structure. In addition, the entities are linked to each other so that users can flexibly browse through the network of information by moving into different directions.

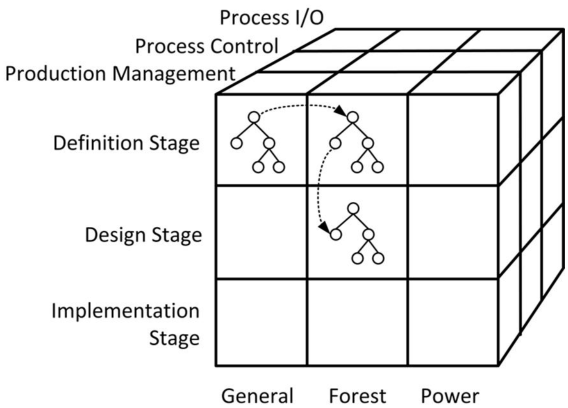

Figure 13. Autaki contents are organized according to several dimensions. (Laitinen et al. 2007; Savioja et al. 2007)

Autaki contents consist of various *content objects*. All content objects use common concepts which are described as metadata. In addition, objects have information attached to them. Content objects constitute *content packages*, which are based on the SCORM specification. This enables to create and buy content packages as products, such as a learning package of some specific technique, industry, or other knowledge, from content providers.

The content of Autaki tool could consist of any kind of materials users need. The ideal use of Autaki occurs when the users update and produce the content, for example, by sharing their knowledge through comments and discussion forums, or by preparing new content packages. Usually the most important and useful information is the information which comes from the everyday work and from the experiences from other projects and engineers. The form of content objects (word, pdf, gif, tif, mpeg, etc.) should not be a problem.

5 Discussion

Automation engineers' work and their competence development are important such as the learning of highly educated professionals in general; for example, electronic engineers' (e.g. Collin 2002, Collin 2004, Jagodzinski 2000, Parsons 1998) and software engineers' (e.g. Finger et.al 2006, Liu&Liu 2008, Rus&Lindvall 2002) learning at work has been studied a lot. Automation engineering has similarities with these and other engineering domains but it has its own features too. One of the most remarkable differences is the central role of automation engineers in a delivering project, such as implementing and delivering a paper machine, a power plant or a harbour crane.

Even though there are a few studies considering the automation engineers' work and learning at work, the understanding of the importance of engineers' competence and knowledge needs to be improved. Comparing the interviews performed in 2005-2006 at companies A and B with the interviews performed at company C in 2012 this change of thinking can be sensed. On the other hand, the differences in how engineers consider the importance of their own competence development can be explained partly by different organizational cultures. Organization is a key for their employees' attitudes towards learning at work and willingness to improve their professional knowledge. By default individual engineers have the willingness to develop their own professional competence and knowledge; by responding negatively for training, an organization can easily suppress the individual employee's willingness to improve his professional skills.

Supporting engineers' learning at work can also be improved by offering a computer assisted learning environment. Knowledge sharing is an essential way to improve individual engineer's learning in teams. Communication via speaking face-to-face or in phone or sending emails is a natural and essential working method in project oriented work environments. Communication usually leads to learning; an individual engineer asks something and learns from an answer. Also well-formed guidance and, for instance, design patterns (which include best practices of design work), along with suitable learning materials support the learning at work if they are easily available. In this thesis I have studied some types of supporting materials and ways to deliver them; there are still many interesting features to study. Especially use of design patterns as a way to transfer one's tacit knowledge into visible knowledge seems to me a promising and interesting approach. Also usefulness of different types of guidance needs to be studied more carefully in the sense of improving engineers' learning and their professional competence.

The basic idea of Autaki tool is still interesting and important; it is even more important today than what it was six years ago. The concept of Autaki, however, requires reform to meet the needs of today. The second edition of AUTAKI prototype should be based on newer technologies, such as web services which improve the flexibility and usability of Autaki tool. Hästbacka has studied web services and engineering process managements in his work. Utilizing Business Process Markup Notation (BPMN) he has developed several methods to process automatically with web services automation engineering design information (Hästbacka & Kuikka 2012b). His approach is potential to be utilized when defining a new implementation of Autaki Tool.

Autaki tool should be integrated into the design tools automation engineers use in their work; with the plugin interfaces of design tools this is possible to be implemented fluently. Integration improves the usability of the tool when it is always available and easy to find and access. Limitations could be caused, for example, the closed or insufficient interfaces of design tools when it is impossible to integrate Autaki into them.

I believe that time is better today for this kind of tool than what it was in 2007. The basic communication tools were same in 2007: face-to-face discussions, phone calls and email were the most popular ways to communicate with colleagues during the projects. But in addition to these methods there was also internal messenger software in company C for their employees. Even if it seems not to be replacing the traditional ways to communicate, younger engineers find it useful in their work. Changing ways to communicate and find new information requires changes in peoples thinking and their ways to perform their work. This again requires time. New generation of automation engineers, those who are recently graduated or are still studying at universities are social media oriented. It would be interesting to see what kind of communication methods this new generation will adopt and does it change the communication traditions in companies.

6 Conclusions

In this thesis it is studied how the professional competence of Finnish automation engineers develops and what kinds of possibilities and obstacles the competence development faces. Due to the fact that control engineering is a special area of design work, results presented in this paper can be generalized partly into some other similar design areas, such as software engineering. However, control engineering has characteristics (e.g. the object of work) different from other design areas.

Both theories of learning at work utilized in this research seem to fit well for studying the competence development of design engineers, such as automation engineers. Theories are dissimilar but not conflicting, instead, they complement each other. Järvinen's and Poikela's theory concentrates on processes which represent entire learning, starting from the learning of an individual and ending to the learning of an organization, and the Core Task Analysis defines the automation engineers' work and its activities and requirements.

18 automation engineers were interviewed – both process automation engineers and machine automation engineers. In interviews we utilized a semi-structured interview method and analyzed the data with work related and learning process methods. As a result, we defined the core task of automation engineers' work, and in addition, we determined the learning demands and opportunities the engineers have.

In the study, the concept of a work support and training tool for automation engineers conducting automation design work was developed based on work analysis. The developed prototype application is an interactive learning environment based on web technology. The users can enter the Autaki application either through a web client or a tool client which is embedded in a design software. The Autaki prototype demonstrates the possibilities of a work support and training tool by implementing some of the main requirements of the concept. The prototype provides information needed in the engineering process, and contains features for collaborative knowledge sharing between engineers.

The Autaki prototype is implemented as a distributed service-oriented application with an interactive and highly usable AJAX web user interface. The prototype also contains a tool client application that proves the integrability of Autaki features in existing design and engineering tools.

The prototype tool was tested and evaluated with professional control engineersBased on the feedback, it seems that the engineers were pleased with the Autaki tool concept and considered it useful in supporting their daily work. The automation engineers also indicated that they would use a finalized version of the tested prototype if it will be available.

According to the feedback, the tool suits best for sharing permanent and rarely changing information such as process descriptions, device manuals, specifications, regulations, and general guidelines within the community of engineers. In order to make the application more useful, additional features, such as the ability to add and edit content through a web user interface, are needed. Another important issue is content descriptions that could be tailored to suit better the specific practices of a company. It can be said that to fully achieve collaborative work support the shared information and content should be produced by the users themselves. Although the study was conducted on automation engineering work, the Autaki concept can be considered to be domain-independent due to the universal features of the tool and used techniques (e.g. SCORM and SOA).

Studying the automation engineers' learning at work and developing the concept and prototype of Autaki tool was an interesting project. During the study I learned a lot about automation engineering in general but at the same time I had an opportunity to expand my knowledge about learning of adults. During the years I have studied the learning of automation engineers and the results of that part I have documented in this thesis.

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